2016

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Entertainment Computing 15 (2016) 21–39

Contents lists available at ScienceDirect

Entertainment Computing

journal homepage: ees.elsevier.com/entcom

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ARTICLE INFO

Article history:
Received 8 April 2015
Revised 17 February 2016
Accepted 18 February 2016
Available online 11 March 2016

Keywords:
Multiplayer real-time games
Human computer interaction
Context-aware computing
Mobile computing
Social engaging games

ABSTRACT

The pre-show experience is a significant part of the movie industry. Moviegoers, on average arrive 24 min before when the previews start. Previews have been a part of the movie experience for more than a hundred years and are a culturally significant aspect of the whole experience. Over the last decade, the pre-movie in-theatre experience has grown to a $600 million industry. This growth continues to accelerate. Since 2012, this industry has increased by 150%. Consequently, there is an industry-wide demand for innovation in the pre-movie area. In this paper, we describe *Paths*, an innovative multiplayer real-time socially engaging game that we designed, developed and evaluated. An iterative refinement application development methodology was used to create the game. The game may be played on any smartphone and group interactions are viewed on the large theatre screen. This paper also reports on the quasi-experimental mixed method study with repeated measures that was conducted to ascertain the effectiveness of this new game. The results show that *Paths* is very engaging with elements of suspense, pleasant unpredictability and effective team building and crowd-pleasing characteristics.

1. Introduction

The pre-show period in the film industry is widely recognized as a good opportunity for advertising. Theatregoers often arrive early to see a movie and furthermore, there are few distractions once they are settled in their seats. This captive audience setting is what advertising companies aim to capitalize on to reach and influence as many attendees as possible [1]. However, an increasing number of moviegoers are becoming dissatisfied and disengaged during the pre-feature period, partly due to the fact that they are aware of their captive status [2,3]. For example, patrons may choose to use their smartphones instead of watching the pre-show or decide to not even go to the theatre at all. Patrons are very aware of the diversity of entertainment options available. In fact, many theatregoers have home theatre environments that negatively influence their movie-going behaviour [4,5].

Movie theatres have a challenge to provide additional value that leverages the social properties of cinema attendance [6,7]. However, now is the right time for the pre-show period to harness the opportunity of social networking and personal interactive technologies [7]. The pre-show period can be reshaped to provide a socially enticing and personally engaging experience instead of driving theatregoers away [4,8,9].

1.1. Research goal

The goal of this research was to create a multiplayer real-time socially engaging game for cinema theatres. An important design requirement was to support all of the major smartphone models currently on the market to facilitate accurately reflecting the reality of the movie-going population. The research plan included the creation of a smartphone app (client) and game server using a rigorous design, development and agile refinement process. The final research objective was to assess the effectiveness of this game using a rigorous scientific method involving a quasi-experimental mixed method study with repeated measures.

2. Background

The section provides a review of related work in the area of multi-player games using handheld devices and large public displays.

Schminky [10] is a multi-player game involving players using their smartphones in a café. A large public display was used to show the social network that resulted from users playing the game.

☆ This paper has been recommended for acceptance by Matthias Rauterberg.

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http://dx.doi.org/10.1016/j.entcom.2016.02.004
1875-9521/© 2016 The Authors. Published by Elsevier B.V.

The degree of collaborative interaction around the large display was minimal and the display was used only as a large scoreboard; furthermore, the game was played exclusively on smartphones as opposed to a client–server model [10]. In a client-sever model some game aspects run on the smartphone, while other aspects run on the large display.

MobiLenin [11] is an entertainment system that allows people to use smartphones to vote on music video clips to be played on a large public display. It was tested in a restaurant, and elicited interesting social behaviours such as spectatorship [11]. In both Schminky and MobiLenin, the majority of interaction was on the handheld devices and between small groups of people who sat next to each other, rather than with the public display and the larger public.

FishPong [12] is a ball- and-paddle style game played on a tabletop display using augmented coffee cups, designed to serve as an *icebreaker*. Similar to Schminky and MobiLenin, the form factor of FishPong's tabletop display makes it more suited to small groups around the table than the larger public display [12].

Flashlight Jigsaw [13] developed an interactive game that is played exclusively on a highly-visible public display, using wireless handheld controllers (not smartphones). The public display also served as the sole shared focus of attention for all players and spectators in a larger public space. While there were many participants (239) involved over the course of the study, relatively few (10) were engaged concurrently. This is quite different than in a cinema theatre environment where significantly more people would be concurrently engaged. Furthermore, the handheld device used was extremely limited compared to the capabilities of current day smartphones.

Eriksson and Jeon et al. [14,15] explored using handheld devices such as mobile phones equipped with cameras to interact with public displays by direct pointing. Belinky et al. [16] studied collaborative planning of a museum visit over a large display using handheld devices. Ballendat [17] studied information exchange between different devices, such as digital cameras, large displays and personal tablet computers in his thesis: "Visualization of and Interaction with Digital Devices around Large Surfaces as a Function of Proximity." In all of these studies however, the number of concurrent users interacting with the large display was very low (less than 8) and the design of the systems were such that interaction amongst the users was not implicitly supported or encouraged.

A study by Ballagas et al. in 2005 focused on enabling interactions with large public displays using mobile phones [18]. They explored various interaction techniques such as the camera's *Point & Shoot* technique and the *Sweep* technique using the smartphones' built-in accelerometer [18]. They built some prototypes to explore these features but did not create a game nor did they provide any empirical results. Ballagas et al. postulated that their prototypes would inspire and enable new classes of large public display applications [18].

One notable recent study by Gruntjens et al. in 2013 showed that social interaction was higher when people are in the same physical area interacting with the same public display. Gruntjens et al. explored two different games for social interaction: First, all players interact at one place [19]. Second, players are spread all over the world while playing the same game. The researchers asked their participants their preference of playing games. 78% of the participants answered they like playing with others using a single large display, while only 50% like playing games while being at different places [19]. The game Gruntjens et al. developed used a public screen showing a virtual shooting range scene while the smartphone touchscreens of all participants displayed an interactive slingshot providing a draggable animated rubber strip. As the taut rubber strip is released, a projectile is shot into the 3D scene onto the public screen (please see Fig. 1). Unfortunately, this game may be only be played by up to four players. This is a severe limitation in terms of scalability and social interaction when designing games for cinema theatre environments where up to 100 players may be engaged—which is the goal of this proposed research.

Another study by Centieiro et al. in 2014 involved creating a mobile multiplayer game called Gaea that explore interaction with public displays stimulate engagement, persuasion and social interaction [20]. Gaea is a persuasive location-based multiplayer mobile game, which prompts people to recycle virtual objects within a geographical area. Players use a smartphone to locate and collect the virtual litter in their surroundings, which should then be dropped into the correct virtual recycle bin, available for selection when approaching the public display [20]. Gaea raises users' awareness to the impact of their actions on our planet's natural resources [20]. It also promotes users' physical activity, social interaction and environmental behaviour changes.

While this research showed encouraging results through user studies that were performed, the purpose is quite different than the research conducted in our work: (1) participants are situated in their theatre seats and do not move; (2) the interaction with the large screen is paramount and central to the game play; and (3) the design for multiplayer interaction amongst the users facilitated by a large display is key in our game but was not a focus in Gaea's design.

A thorough literature review of multiplayer real-time games for movie theatre environments was also conducted. However, extremely few studies were found that could be drawn upon for direct comparison purposes. This may in part be due to the fact that virtually all mainstream cinema theatres have very closed and proprietary systems (e.g., Doremi, Christie cinema servers) [21,22]. Furthermore, there are strict legal agreements that bind the movie theatre company (and, by extension, their display servers) to their movie suppliers in order to show the movies to the public [3,23]. Such systems by design are very secure and closed meaning there are no openly accessible frameworks for application developers to build games. In short, to create any game using these proprietary systems is involved and complex, and in some situations simply not permitted.

The closest notable comparator to the proposed research is Cineplex's TimePlay: http://www.cineplex.com/Promos/TimePlay) [8]. Unfortunately, while there are ad hoc reviews on the games on this platform, there are no scientifically rigorous reviews available at this time.

In summary, these studies indicate that with the increasing prevalence of smartphones, the techniques and approaches discussed could make public display interaction more accessible to the general public, and scale to significant numbers of concurrent users [13,19,20,24].

2.1. Frameworks for the creation of multiplayer real-time socially engaging games for movie theatre environments

A framework is required to create multiplayer real-time socially engaging games for movie theatre environments. In 2011 Deller and Ebert proposed a framework called *ModControl* [24]. ModControl is a configurable, modular communication structure that enables large screen applications to connect with personal mobile devices [24]. Unfortunately, it is entirely theoretical and was not implemented such that application developers could use it [24].

Another framework developed by KPicture Productions Inc. is an open implemented set of libraries for application developers to create interactive content for the pre-movie period. This framework enables any theatregoer with a web-enabled smartphone to quickly and seamlessly participate in big-screen social activities.

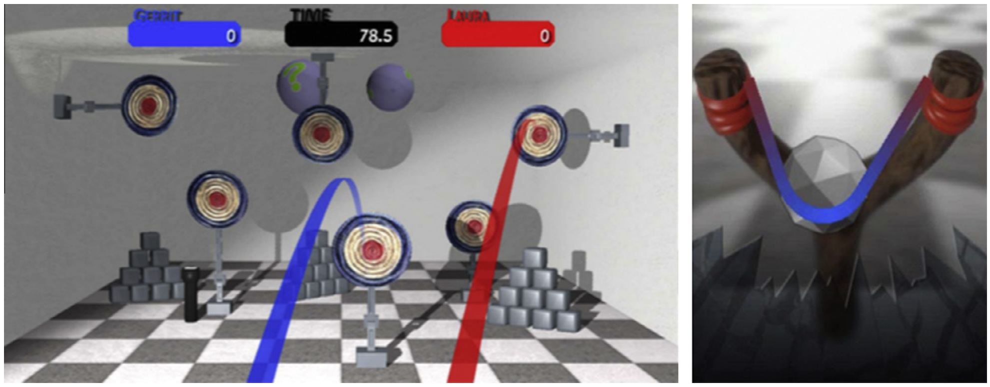

Fig. 1. Left: The large public display. Right: The slingshot on the smartphone (used with permission from [19]).

The framework offers both functional and social benefits such as: *Time and Cost Savings*: The cross-platform framework enables any device that can browse the web to fully participate in the activity; *Simplicity*: since the interactive content is provided by HTML, the time to launch and run the app is at most 1–2 s; *Mobile Culture*: the goal is to engage moviegoers in interactive activities that create excitement, attentional draw and social synergy during the pre-feature presentation. By engaging the audience with mobile devices and the big-screen, theatres can provide an interactive holistic social movie experience for each patron; and *Wide Reach*: Most moviegoers have a smartphone that is Internet enabled. Consequently, the interactive content will reach the largest possible number of theatregoers.

KPicture's framework is an audience interaction technology that allows participants to have an immediate effect on the content with which they are presented. The research in this area is clear: audiences engaged with the content are much more receptive to that content [6,7,25,26]. Furthermore, audiences that engage in interactive behaviour with a common goal feel a greater sense of belonging to that community, and are more invested in the experiences of those around them [23,26,27]. Movie theatres already leverage these benefits of interactive behaviour by providing added excitement to the movie-going experience [23,25]. Audience interaction offers many potential benefits in the pre-show event [1,23,26] including, an interactive, engaging and exciting environment; improved movie-going experience; and greater receptivity and impact of pre-movie content and/or advertising.

In designing the game, several desirable characteristics were i dentified—characteristics that are well-defined and have been used in other related works [13,18,20]; they are: *movie theatre contextual environment* (multiplayer real-time interaction); *ease of learning* (movie-goer must be able to learn the game quickly and easily); *ease of use* (leverage movie-goer's familiarity with their own mobile device); *crowd engagement* (game needs to appeal to a wide audience to generate crowd engagement); *creation of team spirit* (collaboration) and *rivalry* (team competition); *feasible* (game must be able to be created within a 6-month period [external requirement], and *run on as many different smartphone devices as possible* [via smartphone's browser]); and *scalable* from 2 to 100 moviegoers.

The outline of the remainder of this paper is as follows: candidate games for the theatre environment, game design, methodology (including the method used for game refinement and the scientific method used to evaluate the game), findings and analysis, discussion and conclusion. The findings and analysis are based on sound empirical results and the conclusion includes guidelines for generalizable contribution.

3. Candidate games for this research

The desirable characteristics (design requirements) for the game were used in assessing the suitability of candidate games. These design requirements are presented in Table 1. The following candidate games were considered on the outset before commencing prototype design and development.

Candidate Game #1: A Racing Car Game in which the design of the game involves cars and racing lanes shown on the cinema screen. Each player would see two buttons to control his/her speed of the car on his/her smartphone. Each player would be able to see their own lane and the hurdles that they will need to pass through to reach the finish line. Racers have the ability to either aid or impede other racer's progress (depending on if they are a member of a team or not). When a hurdle is reached, a brief quiz is presented on the user's mobile device that they must answer in order to proceed. If the question is not answered in a timely fashion or not answered correctly, their progress is impeded.

Candidate Game #2: A Maze game in which the cinema screen displays the entire maze, including obstacles, collectables, and all the players in the game. On the player's smartphone, the player can also see the entire maze on their mobile device but only a neighbourhood section at a time—due to the limited screen real estate. Each participant controls his/her character and attempts to move that character from a starting point to a finishing point in the maze.

Candidate Game #3: A Visual (musical) Performance in which the game initially starts as a solid coloured screen (black, white, etc.). Rhythmic music starts to play after a short instruction display. A random geometric shape in a random position on the theatre screen is assigned to each of the participant's mobile device. When the participant taps the screen of his/her device, the shape will visually pulsate. With the introduction of the music, each participant will be responsible for tapping his/her smartphone's screen to the correct tempo. This will create a visual presentation of every one's shape pulsating to the beat of the music.

Candidate Game #4: Paths: This game involves a rectangular playing field with players from each team positioned along the opposite sides. Each player is represented by a round coloured piece with their player number displayed on it. Players will traverse a pre-defined curved path from one side to the other (e.g., from the left to the right). On the participant's device, players will be presented with an interface that allows them to join the game, trace a path with their fingers, speed up or slow down while their piece traverses their path, and throw a ball to another player on their team. Players are prompted to draw a path on their mobile device from one end of their screen to the other. This path will

Table 1
Desirable characteristics for pre-movie games.

Criteria #	Criteria title	Description
1	Movie theatre context	The game needs to appeal to the movie-goer, intuitively fit the multiplayer real-time interaction paradigm and be socially engaging
2	Ease of learning	The game needs to be easy to learn for the movie-goer. For the game to be classified as easy, the skill and knowledge required must be already acquired by the participant or be acquired within 20 s of instruction [28]
3	Ease of use	The human computer interaction required for the participant to perform the game must be easy to use (e.g., simple intuitive smartphone interactions such as, pressing the left or right buttons to move left or right). For the game to be classified as easy to use, the time required for a movie-goer to learn how to properly interact with the game to successfully accomplish the task is 20 s or less for someone with no prior knowledge aside from basic smartphone competency—this length of time is based on similar studies in computer task analysis in the HCI field [28–30]
4	Crowd engagement	The game must balance the movie-goer's attentional focus between his/her smartphone and the large cinema screen, with particular emphasis on attentional draw from the smartphone (game controller) to the large screen—where game play takes place and crowd engagement is set to occur
5	Creation of team spirit	The game must have incentives to ensure team-building characteristics. For example, randomly grouping movie-goers into *Team A*, or *Team B* and providing friendly game rivalry elements to build team collaboration (within a team) and team competition (between teams)
6	Feasibility	The game must accommodate as many smartphone devices as possible. The game also needed to be feasible in terms of complexity – we had a fixed time of 6-months to build, test and evaluate the game involving a team of 3 people working part-time on the project
7	Scalability	The game must be able to scale efficiently and effectively from 2 to 100 movie-goers without the loss of generality (i.e., all other desirable characteristics are upheld and core functionality remain intact)

be translated to the big screen where each player's piece will traverse this path until it reaches the opposite side of the playing field without colliding with a player from the opposing team. The player uses the mobile device's game interface to control the speed of their piece during each round. Also, during each round, a ball is given to one player from each team, which is to be carried through to the opposite side by a successful combination of passing and dodging manoeuvres.

4. Game selected for this research

Detailed sketches and storyboards were created for each of the candidate games. A focus group was established that involved four people with game critiquing experience (median age of 25 [mean 25.5, min. 22, max. 30]), to evaluate each of the proposed games against the seven criteria identified in Table 1. Each of the members of the focus group was independently asked to complete a survey consisting of a description of the candidate games followed by a set of questions (7 questions * 4 games = 28 questions in total per survey). The survey responses were based on a 5-point Likert scale (1 = very unsuitable, meaning the candidate game would very unlikely satisfy that characteristic vs. very suitable = 5, meaning the candidate game shows great promise to satisfy that characteristic). Each of the members in the focus group were asked to carefully weigh each of these candidate games against the design requirements when completing the survey. The results from each survey were aggregated together using standard mean calculations that are summarized in Table 2 (the means are presented in "()").

The results showed that the *Paths* game had the greatest potential from the focus group's perspective to most effectively satisfy the desirable characteristics. The most significant reason why the other games were unsuitable is because they did not satisfactorily meet the *scalability* desirable characteristic. For example, in the Racing Car Game, it was envisioned that the when 20 or more cars move around a racetrack on large display it would become very confusing and hard to distinguish between cars. This would be particularly so if the cars were bunched up together, as typically happens in races of this nature. Similar conclusions were drawn from the analysis of the other games (i.e., Maze Game, Musical Performance) in terms of poor scalability potential.

The following section presents the features of *Paths* relative to the desirable characteristics: Ease of Learning, Ease of Use, Crowd Engagement, Creation of Team Spirit, Feasibility and Scalability.

Ease of Learning: Frequent instructions on the big screen will guide the player through the learning process, including path drawing, *speed control* and *ball passing*. The game itself progresses through rounds of increasing activity and complexity to ensure that players are eased into learning the game without difficulty. For instance, to facilitate ease of learning, the first several rounds of the game simply involve the users to watch the big screen. After these rounds, *speed control* is introduced and then for the final set of rounds *ball passing* is presented as an option during game play. This approach is based on reducing the cognitive load of users while they are acquire new knowledge of game play [31,32].

Ease of Use: Players know how to interact with their own mobile devices. This game relies on the player's knowledge of interacting with the touch screen in a web interface on his/her device. The client controller is a web browser built using HTML and JavaScript technologies. Frequent prompts and instructions are presented to the user in order to facilitate ease of use and intuitive game interaction. The Ease of Use desirable characteristic is a reflection of the fine-motor skill acquisition activity to play the game. Studies show that the ease with which one interacts with his/her device (and/or app) is a unique and determining factor in the overall user experience and satisfaction in using that app [33].

Crowd Engagement: The game requires modest player attentiveness throughout each round in order to have successful results. Players are encouraged to keep their eyes on the big screen during round play to interactively engage their fellow teammates as well as those from the opposing team. The speed control and ball passing features are gradually introduced to the player during later rounds to ensure appropriate and incremental increase in difficulty level. This design of difficulty level is aimed to be proportional to the level of fun and engagement the player experiences.

Creation of Team Spirit: To encourage team spirit, ball-passing rounds were introduced in the game. One player of each team is randomly given a ball with the objective to pass it to another teammate (and then potentially to others on the team) and successfully reach the end zone. With each pass, the team earns points. If the team successfully gets the ball to the end zone, additional team points are awarded.

Feasibility: From the outset, the game design was fundamentally sound in that it could accommodate many smartphone devices and was not overly complex (easily fit within 6-months period to build, test, evaluate and refine). The communication framework (client–server), Unity3D framework (game server)

Table 2
Evaluation results of candidate games against desirable characteristics.

	Movie theatre context	Ease of learning	Ease of use	Crowd engaging	Team spirit	Feasibility	Scalability
Racing car game	✓✓ (3.75)	✓ (3)	✓✓✓ (4.75)	✗ (1.5)	✓ (3.25)	✓ (3)	✗ (1.5)
Maze game	✓ (3)	✓✓ (3.75)	✓✓✓ (4.75)	✗ (1.5)	✓✓ (3.75)	✓ (3)	✗✗ (0.75)
Musical performance	✓✓ (3.75)	✓✓✓ (4.75)	✓✓✓ (4.75)	✓✓ (3.75)	✓✓ (3.75)	✓ (3)	✗ (1.75)
Paths	✓✓✓ (5)	✓✓✓ (4.75)	✓✓✓ (5)	✓✓✓ (4.75)	✓✓✓ (4.5)	✓✓✓ (4.75)	✓✓✓ (5)

✓✓✓: very suitable, ✓: suitable, ✗: unsuitable, ✗✗✗: very unsuitable, –: not applicable (means of the 5-point Likert scale responses in "()").

and mobile device interface (HTML/Javascript client controller) were all well understood by the team.

Scalability: The game can be easily scaled from 2–100 players. This is accomplished in three ways: (1) reducing the size of the player's piece on the theatre screen to comfortably fit all the players; (2) lining up the pieces on each team vertically on each side of the screen, column by column until all the pieces are placed (see Fig. 2); and (3) to avoid confusion, particularly for large groups of 50 or more participants, identification is accomplished by showing the player's number and colour on each piece on the cinema screen (which is also shown on the player's mobile screen).

5. Game design

This section discusses the game design and contributing factors that led to the development and refinement of the game. The game area consists of a rectangular space representing the large cinema screen and this view is represented on the smartphone in landscape orientation. There are two teams – Team A, located on the left side of the game area and Team B located on the right side. Each player is represented by a unique number and coloured circle. The player's pieces are randomly positioned and lined up vertically in teams. Fig. 2 depicts the layout of the game with 14 players. Fig. 3 presents the smartphone screen for when a player is asked to draw a path by using their finger from their piece (circle) to the opposite edge of the game area (end zone). Because of the gross scale differences between the smartphone and cinema screen, the position of the piece on the smartphone is relative to the player's position on the large screen. As shown in Fig. 3, player #1 is on Team A (left side of the screen) and located near the top of the cinema screen.

Once all players have finished drawing their paths (each player can only see their own path while they are drawing it on their smartphone), the game begins and the player's pieces start moving along their pre-determined paths at a fixed speed (see Fig. 4). The object of the game is for players to build paths that they can hope will not cause a collision with another player's piece during the execution of the round. This will be mostly guesswork because players will not know beforehand how the other players will drawn their paths nor will they have any control over the speed. This design was purposeful so that during the initial rounds players would get a feel for the game and the audience's behaviour.

Players can decide what constitutes a better and safer path to take in future rounds and thus reduce the feeling of randomness when playing. When a collision occurs, popcorn pops out from that location and quickly disappears, the players involved will automatically lose the current round and be temporarily stuck together in place allowing the possibility for collision with other players who are still active.

5.1. Scalability

In an effort to accommodate for the variable nature of moviegoers participating in the game, for each new player that joins the game, the player's pieces decrease in radius to accommodate these new arrivals. This also ensures that when there are only a handful of players, the level of challenge is maintained (as bigger pieces increase the chance for collisions to occur during gameplay). The potential issue of identification when accommodating large number of players (say 50+) was mitigated by a well-defined identification strategy. Players are identified by their unique coloured piece and their unique number shown on the piece on the smartphone (see Fig. 3) and on the cinema screen (see Fig. 2).

5.2. Game modes

There are four modes in the *Paths* game; they are:

1. Simulation
2. Sit-back and Relax
3. Varying Speed
4. Varying Speed and Ball-Throw

In cinema theatres, it is possible to have very few patrons attending the pre-screen event before the movie starts. Consequently, *Paths* was designed to offer a simulation mode during which the game runs if no player is present or not participating in the game. We felt this design offered visually stimulating entertainment in such circumstances. In *Simulation* mode, 20 AI players are created and traverse random paths at a constant speed. The result is a unique colourful collage of various intertwining paths and is entertaining to watch.

In *Sit-back and Relax* mode, each player's piece moves at a constant speed for the duration of the round. Players draw their paths on their smartphones, *Sit-back and Relax*, and watch the show. This is the design of the first few rounds to help players become accustomed to the game and its underlying concept. Fig. 5 presents the smartphone screen while the round plays out on the cinema screen.

This mode also provides players with an opportunity to become familiar with the playing style of other participants.

In the second half of the game, it enters a new mode called *Varying Speed* in which players will have the ability to strategically increase or decrease their speeds along their drawn path to further influence the outcome of the game. Fig. 6 presents the interface for this mode showing the discrete course-grain speed intervals facilitating minimal attentional focus on the smartphone since the player is watching the action on the cinema screen.

After several rounds of *Sit-back and Relax* and *Varying Speed*, the game changes to the *Varying Speed and Ball-Throw* mode. During these rounds, a ball is randomly given to one player on each team. The goal is to pass it to another player on the same team (who in turn may pass it to another teammate etc.), and reach the end zone. Incentives are built into the game to encourage passing as it builds team and individual points. Fig. 7 depicts the interface for the *Varying Speed and Ball-Throw* mode. Note the speed control on the left is essentially the same as the *Varying Speed* mode to

Fig. 2. Initial game layout with 14 players involved. Each player is uniquely identified by colour and number. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

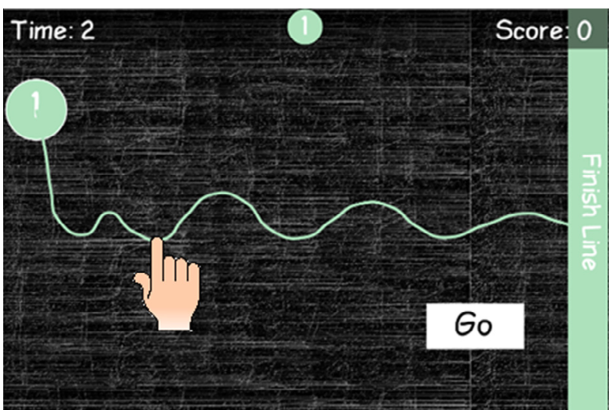

Fig. 3. Path drawing on the player's smartphone using their finger from where their circle is to the opposite edge of the game.

Fig. 5. Smartphone display when game is in *Sit-back and Relax* mode (initial rounds of game to provide ease of learning).

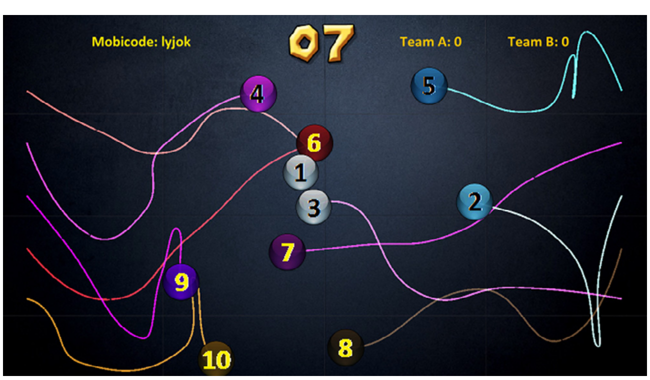

Fig. 4. Player's pieces in motion during gameplay. The paths left behind each piece are the same colour as the piece. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

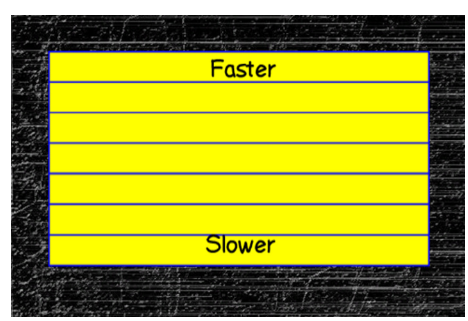

Fig. 6. Varying speed mode. Using the smartphone as a controller, the player can increase or decrease the speed of his/her piece during gameplay.

provide continuity in learned skills for the game. On the right is a dial control that allows the player to aim and then press the *Throw* button (centre of dial control) when ready to pass the ball.

5.3. Scoring

There are five events that award points to players. Points are awarded to players who reach the end zone and they receive additional points if they have a ball in hand. Beyond simply trying to just get across, we incentivized the players to pass the ball around to their teammates in an effort to generate team spirit. Therefore, points are also awarded for successfully passing the ball as well as receiving it. Lastly, points are awarded to players when they collide with an opponent. The more opponents a player collides with and hence takes-out of the round, the more points that player receives. Team scores show the total points earned by players on their respective team (see Fig. 4). Table 3 presents the scoring and point system in *Paths*.

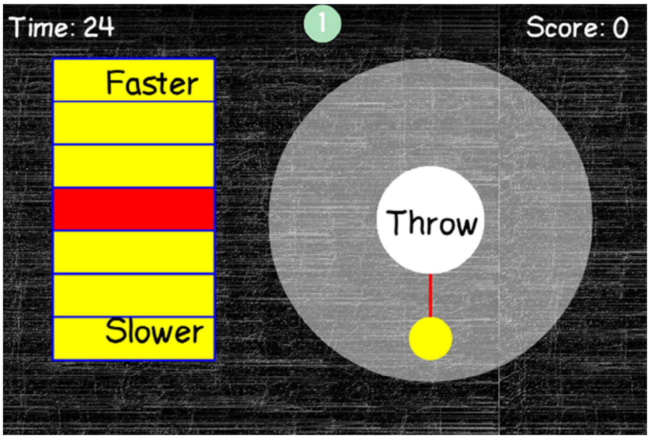

Fig. 7. Smartphone view of *Varying Speed and Ball-Throw* mode. Note the dial to aim and the "Throw" button to throw the ball in the set direction.

6. Methodology

The methodology employed in this project is supported by two distinct research components. The first component is related to the manner in which *Paths* was designed and developed. In this component of the research methodology, the results from pilot studies and experimentation provided insight for the improvement of the game. The new knowledge was fed back into the refinement of *Paths*. Beyond the initial development of *Paths*, an agile development process was used: design, develop, test, modify, redesign, redevelop, retest, etc.

The second component of the methodology is related to the manner in which *Paths* was evaluated from a scientific rigorous approach. The research methodology for this section involved a quasi-experimental mixed method study with repeated measures. This research study was a quasi-experimental design because we could not guarantee random selection [34]; it was a mixed method study because both qualitative and quantitative instrumentation was used [34]; it was a repeated measures study since there were several phases of evaluation (*Paths* was revised and updated after each iteration) [34].

This section describes various aspects of the methodology including: Game Design; Pilot studies; Participants; and Experiment Procedure.

Methodology Component #1: Method by which Paths was designed and developed

This section presents the initial design of *Paths* and the methodology for improving the game along the seven desirable characteristic dimensions (see Table 1). This involved both qualitative instrumentation (i.e., researcher observation and note taking) and extensive client–server log data that was captured throughout the experiments including:

- client ID
- client and server messages and message type
- path data for each client
- client and game states
- number of players joining and leaving
- keep alives
- keeping track of AI vs. human players and current vs. future players
- keeping track of teams
- how players are laid out on the cinema screen
- which player gets a ball initially

Table 3
Scoring in *Paths*.

Scoring event description	Points awarded (individual)
Reaching the end zone	10
Colliding with an opponent	1
Passing the ball	5
Receiving the ball	1
Reaching the end zone with ball	30

- which player throws the ball
- which player received the ball
- when different phases of path construction are completed and details about those phases

The remainder of this section presents the *game design—architectural model*; the *game server*; the *client-side design*; and the *game server path construction*.

6.1. Game design – architectural model

This section presents the architectural model of *Paths*. One the of overarching design considerations for the architecture was to create a model that was independent as much as possible from any game specific considerations. For example, the model provides fundamental support for communication between the Game Server and Mobile Device clients and abstracts as much as possible details surrounding game specifics. It also provides the framework by which scalability is an inherent design requirement theoretically supporting up to 500 concurrent players (based on the computational resources required and the network bandwidth throughput to support intense client and server communication). This architecture provides the foundation for a whole host of other cinema-based games using smartphones may be created—all using this common architecture. Our framework is publically available via BitBucket and can be easily downloaded from the Internet for anyone use in developing games for cinema theatres [35]. In this way, generalizability and appropriate reuse may be achieved. Figs. 8–10 visually present this architecture and are explained below.

Fig. 8 presents the client-sever architectural model designed and developed to support the *Paths* game. The Game Server and Mobile Device client core communication components. The main class that handles all outgoing and incoming communications is AIPEventDispatcher. This class interfaces with the AIP network to send and receive data from the mobile clients. We also implemented an internal event messaging system that acts as a "post office" for events that are raised by a sending object and listened for by a receiving object instead of direct messaging, thus decoupling some the game objects from each other during runtime. Two types of events were designed to be used with this system: game events and network events. Game events are strictly used for internal communication (i.e., within the server). When a Unity object raises a network event, important data is packaged into the event object so that the event dispatcher that is listening for these events can then extract their contents before communicating with the client.

A typical example of outgoing communication occurs when a player is positioned on the screen at the beginning of a round. A `PlayerArrangedEvent` would be raised by the `PlayerManager` at this point and it will contain the player's client ID and normalized x and y position coordinates. The event dispatcher receives the event (via the event messaging system) and then sends a `MessagePlayerArranged` message to a specific client with their position information so that the client can position the player's piece on the mobile device screen.

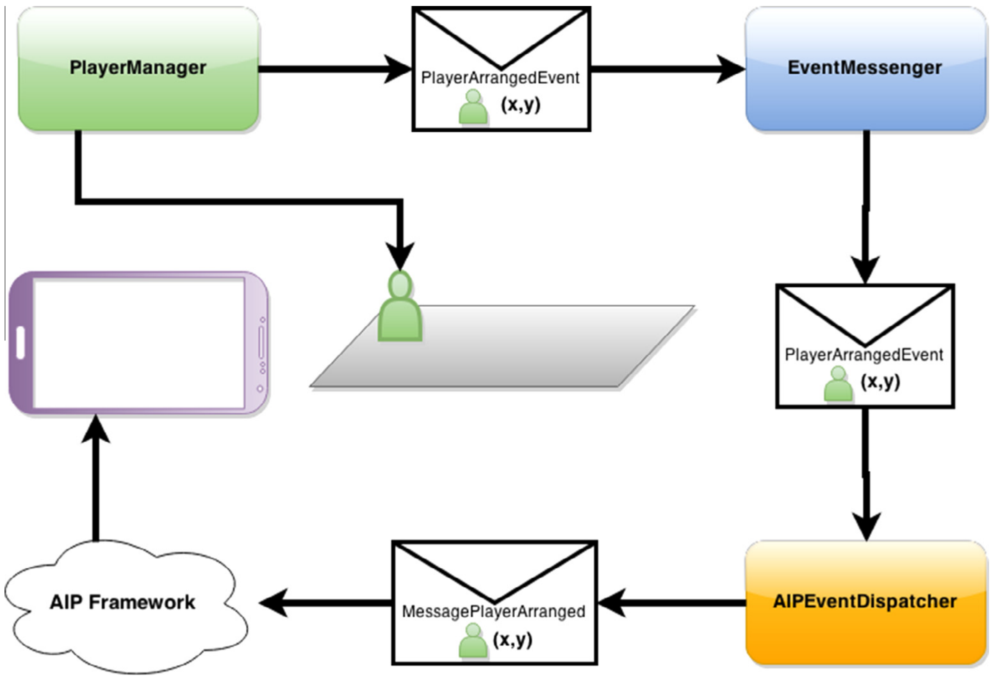

Fig. 8. High-level *Paths* client-sever architectural model depicting core client-server communication.

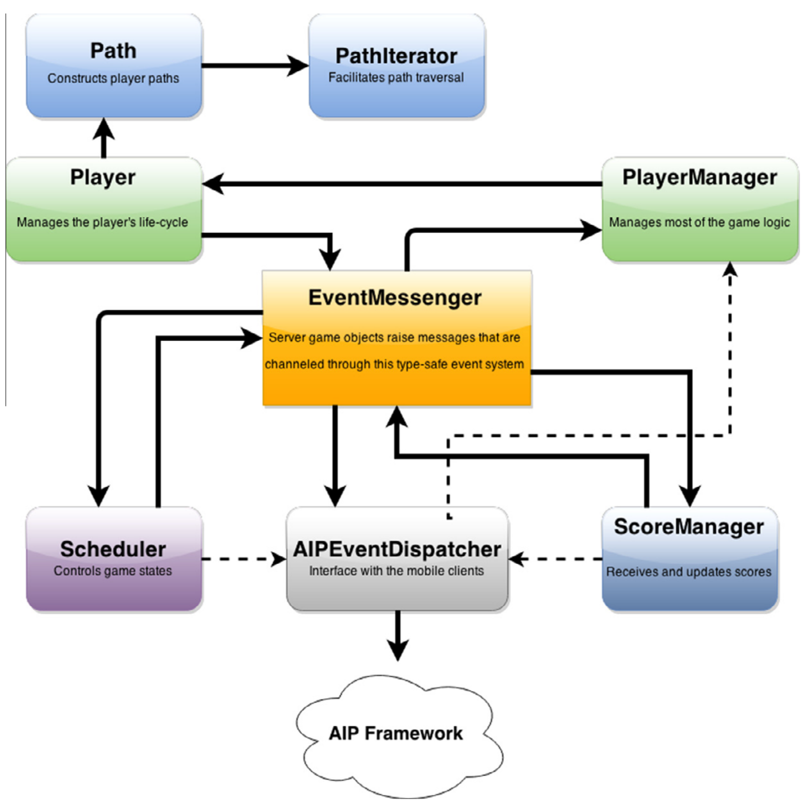

Fig. 9. High-level *Paths* architectural model depicting core functionality: scheduling of game events and dispatching of messages to mobile device clients and game server.

The dispatcher also handles incoming communication via the callback method `eventMessage(string name, string data, string clientId)` which handles incoming messages from all clients. Messages are identified by name and client ID and then added to a queue which is then processed sequentially in the game's `update()` loop. Then, the event dispatcher will pass information to the appropriate game entity.

6.1.1. Game server (unity server design)

The main classes that support the game logic are described below and depicted in Fig. 9.

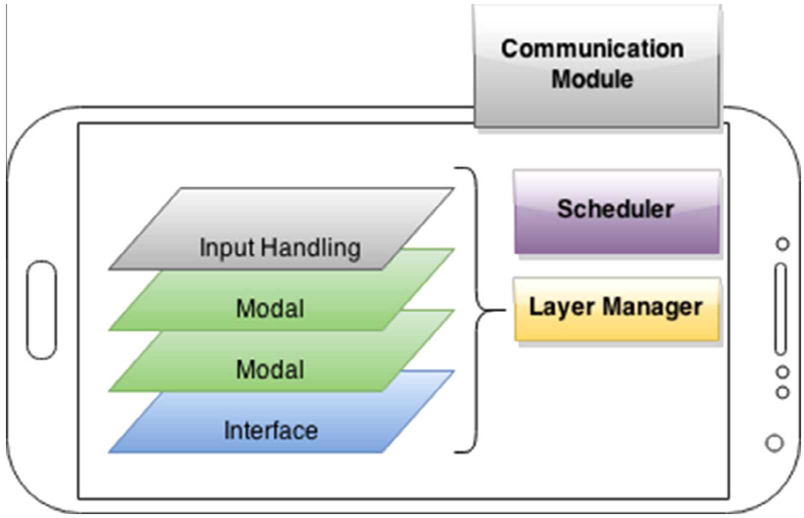

Fig. 10. Architectural model for the mobile device client.

1. *Player:* Handles all of the player states (i.e., moving, stationary, and shrinking), collisions, speed, ball throwing, and ball receiving. Player will have a reference to a `Path` object and `PathIterator` object.
2. *Path:* Contains all the logic for drawing the path (using a `LineRenderer` object and algorithms for drawing Bezier curves using control points that are either provided to it by a client or randomly generated).
3. *PathIterator:* Contains the logic for getting a player to actually traverse his/her path with a constant speed, which is not dependant on the underlying architecture of the path.
4. *PlayerManager:* This class provides the main functionality for the game by managing all player interactions, layout, player lists, teams, AI players, registering new players, and facilitating communications between a player and the event dispatcher.
5. *Scheduler:* Manages the overall game states, timing, loads different scenes, and informs the `PlayerManager` of state transitions via the messaging system.
6. EventMessenger – Server game objects raise messages that are channeled through this type-safe event system.
7. *AIPConnection* – initiates the connection with the game server.
8. *AIPEventDispatcher* – facilitates the submission of events through the AIPConnection.
9. *ScoreManager:* Manages all scores in the game (i.e., collisions, goals, and ball throwing).

6.1.2. Client-side design

The mobile device client for *Paths* was designed as an HTML5 canvas web app. The architectural model is presented in Fig. 10. Perhaps the most significant component of the client is the *Communication Module*. This module is responsible for all incoming and outgoing messaging between the client and the server. Information, such as where a player is positioned initially, which player has the ball, the player's score, is collected and sent to the client. The client mainly sends player control events, but also sends `KeepAlive` packets at certain points in the game to let the server know that they are still active, as to not be placed out of the next round.

The client has a scheduler like the server, but its role is different. One of its purposes is to anticipate state changes from the server. Knowing the time period of each state, it can conclude that a network connectivity issue is present if a state change does not happen when expected. When this happens, it will trigger a connectivity issue modal telling the user of the problem. Another purpose for the client's scheduler is to display the time a latecomer has to wait before entering the game. The total time to wait is known by summing the time periods for all the game states until the next round starts.

The web app also manages the display and removal of several different Interfaces. Interfaces are activated depending on the state the game is in currently by the `Layer Manager`. At any given point in time, the server informs the `Layer Manager` what Interface to present to the player. On top of Interfaces, the `Layer Manager` can also display *Modals* that block interaction with the Interface on the layer below. Modals are used to indicate waiting times for latecomers to the theatre (as can be expected for typical for movie-goers). Modals are also used to indicate connectivity issues with the server.

6.1.3. Game server path construction

From the user's perspective, a path is simply a continuous smooth curve with two endpoints. From a development perspective, a path is nothing more than a sequence of points. The problem was how to capture this sequence from gesture input, transport this data across the network, and unpackage it on the game server so that it could be rendered on the cinema screen. The following section describes our solution.

Determining the most efficient and effective way to communicate the sequence of points across the network required a significant amount of research in this project. The number of points to be sent and received for potentially hundreds of clients in movie theatres could put a heavy load on the network and server. A design focus was to reduce this communication to a minimum and transmit only the necessary information to be able to fully reconstruct the curve. The Bézier curve algorithm was used for this purpose.

A Bézier curve is a parametric curve frequently used in computer graphics and related fields [36,37] (please refer to Fig. 11). In vector graphics, Bézier curves are used to model smooth curves that can be scaled indefinitely [36,37]. "Paths," as they are commonly referred to in image manipulation programs, are combinations of linked Bézier curves [36,37]. A Bézier curve is defined by a set of control points P_0 through P_n, where n is called its order ($n = 1$ for linear, 2 for quadratic, 3 for cubic, etc.) [36,37]. As the curve is completely contained in the convex hull of its control points, the points can be graphically displayed and

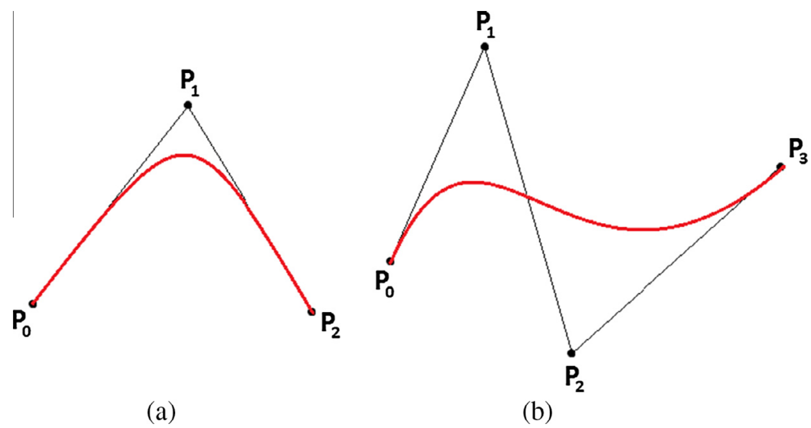

Fig. 11. Bezier curves – an integral part of *Paths* for rendering the movement of pieces along a curve on smartphones and on the large cinema screen. Each Bezier curve is uniquely represented by the position and number of *control points* (e.g., (a) curve represented by control points: P_0, P_1 and P_2, and (b) curve represented by control points: P_0, P_1, P_2 and P_3).

used to manipulate the curve intuitively [36,37]. Quadratic and cubic Bézier curves are the most commonly used (as shown in Fig. 11). The control points uniquely determine the curvature of the path – all other aspects of the paths are extrapolated by using the algorithm [36,37].

In our solution, the coordinates of the Bézier control points are normalized before being sent to accommodate for the differences in screen dimensions between various mobile devices and the cinema screen. The points are then de-normalized and scaled appropriately upon receipt.

On the client side, points are captured via a custom touch handling mechanism and rendered to the mobile screen using a JavaScript line rendering framework that uses a Bezier curve algorithm behind the scenes. The same technique was used on the game server for rendering on the cinema screen.

Methodology Component #2: Method by which Paths was evaluated from a scientific rigorous approach

6.2. Pilot studies

The pilot study was a complete representation of the whole experiment—that is, each participant in the full experiment was exposed to the same treatment from introduction to debriefing as participants involved in the pilot study. The rationale for conducting a pilot study is explained below:

- To determine the appropriate number of and timing of rounds within the game.
- To set the game difficulty to the appropriate level for the population base.
- To determine the appropriate number of AI players to ensure the game remains challenging and interesting (e.g., the game should remain interesting if only 2 people are playing and equally so when 50 human players are playing).
- For reliability purposes—to ensure that once the pilot studies were completed, the experiment would run consistently and the results would be as reliable as possible.
- To understand the strategies and tactics relating to the participant's gameplay style. The goal here was to shed some light on the following questions: What are the strategies being used in different situations? How could we learn from these game behaviours to generate more crowd engagement and excitement? What are the issues (both major and minor) that need to be resolved before the main experiment?

A video of one of the researchers testing *Paths* before the pilot study is found here: http://www-acad.sheridanc.on.ca/~sykes/research.html

6.3. Participants

A total of 48 volunteers were participants in this experiment (10 involved in the pilot study, 6 in main experiment #1 (median age of 20.5 [mean 22.3, min. 18, max. 32]), 16 in main experiment #2 (median age of 25 [mean 25.6, min. 18, max. 54]), and 16 in main experiment #3 (median age of 19 [mean 19.3, min. 18, max. 22]). All participants were sampled from the general population of Sheridan Institute of Technology and Advanced Learning, Oakville, Ontario, Canada. Participants were recruited by a set of posters at various locations throughout the campus. Furthermore, an email broadcast was also sent to all the faculty members in the School of Applied Computing in the Faculty of Applied Science and Technology to let students know of this opportunity. The recruitment message did not disclose the purpose of the experiment, but described the task as fun and similar to a video game. The message also indicated that each volunteer would receive compensation for his or her time and that volunteering would be a significant contribution to the advancement of science. This method for population sampling is less than random (thus is classified as a quasi-experimental design). However, it was deemed adequate because of the diversity of the Sheridan College student population, the location of the college with respect to the Greater Toronto Area, and because of the motivation of the compensation upon completion of the experiment.[3]

6.4. Experiment procedure

Participants were coordinated to meet at a specific time and theatre location on the Sheridan campus. A script was followed to ensure that each of the experiment was treated in a consistent fashion. This script is shown in Table 4. Each participant was expected to take between ½-h and 1-h to participate in the experiment.

[3] Compensation for this type of research in HCI is similar to other studies. Please see: Scheirer, J., Fernandez, R., Klein, J., & Picard, R. W. (2002). Frustrating the user on purpose: a step toward building an affective computer. Interacting with Computers, 14, 93-118. (compensation : $10 USD), Iqbal, S., & Bailey, B. (2006). Leveraging Characteristics of Task Structure to Predict the Cost of Interruption. Paper presented at the CHI 2006, Montreal, Quebec, Canada. (compensation: $5 USD).

The Closing Questionnaire was the main instrument for collecting qualitative information in this study and is shown in Appendix A.

7. Findings and analysis

7.1. Pilot study findings

At the time of the pilot study, the *Paths* game was a beta version in that it had all of the game modes implemented: (1) Simulation, (2) Sit-back and Relax, (3) Varying Speed, and (4) Varying Speed and Ball-Throw, however, there were some limitations. In this version, *Paths* did not track or present individual scores and there were no onscreen instructions. One of the purposes of the pilot study was to determine the appropriate number of and timing of rounds within the game. We discovered that there were too many rounds and the timing of rounds was slightly too long. We also found that since there were no onscreen instructions, some participants were confused at the beginning. However, after a couple of rounds, all of the participants appeared to be engaged and interacting comfortably with the game.

A second purpose of the pilot study was to set the game difficulty to the appropriate level for the population base. The difficulty of *Paths* is directly proportional to the number of players (human and non-human), the size of the pieces and the speed with which they move. The number of AI players can be easily adjusted and directly influences the difficulty and strategy human players exhibit. AI players during the pilot study followed a random path and traversed it at a steady and predicable speed. As mentioned earlier, *Paths* was designed to function in simulation mode if no player were present. This mode provided great opportunities to conduct extensive experimentation without involving human participants. Consequently, we were able to conduct a variety of experiments to determine the impact of adjusting the number of AI players with: (1) the number of collisions that occurred and where, and (2) the number that successfully reach the end zone.

Table 5 presents a summary of the success rate statistics for AI and human players. We felt the game was sufficiently challenging yet not overly so to cause despair or frustration.

Another factor that we considered during these simulation experiments was to determine the appropriate number of AI players to ensure the game remained challenging and interesting when scaled. For example, the game should remain engaging and interesting if only 2 people are playing and equally so when 100 human players are playing. These findings provided guiding principles to set the game difficulty level when human players are involved in the game.

Another purpose for the pilot study was to evaluate *Paths* from a stability and reliability perspective. We wanted to make certain that once the pilot studies were completed, the experiment would run consistently and the results would be as reliable as possible. For example, initially, we followed a more naive approach for Bézier curve traversal. We traversed the points on the curve at a constant rate, not taking into account that points were not laid out equidistantly on the curve. There were more points around areas of high curvature and because the randomly generated paths constructed for AI players were different than human created ones, there were significant differences between the rate at which human players and AI players moved. We solved this problem by a `PathIterator` object (see Fig. 9). This object manages its position along the curve and the index of the point it is on, and by keeping track of the distances of each line segment between the points, it can move along those segments and make sure it moves exactly the amount of distance allowed.

The following section provides selected comments from participants in an effort to uncover common elements regarding benefits and/or problems with playing *Paths*. The pilot study also served as a means to uncover low-level technical issues and high-level game logic issues in an effort to fully reach all of the desired characteristics (see Table 1).

Positive comments:

1. "Great idea! Simple, elegant, challenging, but rewarding. Teamwork is required."
2. "Very interactive."
3. "It was super fun!."
4. "*Paths* has great potential – it just needs additional clarity (i.e., instructions). Good job!"

Negative comments:

1. "Fairly easy to learn how to play, but instructions would make it incredibly simple to learn."
2. "Unclear what the goal of the game was."
3. "Hard to play it properly because there were no instructions."
4. "When drawing [on the mobile device] the draw board is slightly obscured by the information bar and it is not intuitive that you can draw your path there."

Beyond the comments gathered from the participants, statistical analysis based on the closing survey was also performed. Table 6 depicts the summary statistics of this qualitative survey. There were a number of interesting observations that result from the analysis of this data. The following are the most significant ones.

1. 93% of the participants felt they were "engaged" or "very engaged" while playing the game.
2. 93% of the participants felt the entire audience was "engaged" or "very engaged."
3. 57% of the participants responded that the game was "easy to learn."
4. 40% of the participants felt the game was "easy to play."

These findings provided opportunity and justification to explore how to refine *Paths* in very focused ways to ensure that the next version would address the negative comments and attempt to enhance the positive ones too. Furthermore, numerous technical issues were identified by the researchers captured in researcher logbooks that facilitated cross-referencing with server and client logs that were recorded during the execution of the pilot study. This approach facilitated very accurate analysis of the technical issues and their resolution.

Some of the issues identified at this stage were:

1. Each player starts from one side of the screen (represented by Team A or Team B). However, each player had a unique colour. Although it was clear from the outset who was on who's team, during game play the cinema screen became a collage of a different coloured pieces moving about, making it difficult for players to determine who was on who's team. This also made it difficult for "team building" to occur since there was no underlying mechanism to support relationship building.
2. Game play instructions would be beneficial to ease learning and aid in playing the game initially.
3. On the client, occasionally, the ball throwing controls would show a ball even though on the cinema screen a ball was not showing as associated with that player and vice versa.

These problems were diligently worked on, refined and tested in the laboratory until we felt the game was sufficiently improved and stable for another participant based experiential study (i.e., main experiment #1). Specifically, we worked on:

Table 4
Researcher script for conducting experiment.

1. Greeting and introduction
2. Acquire participant's signature on a consent form that explains their rights.
3. Administer participant Opening Questionnaire.
4. Ask participant to sit and open a browser on his/her mobile device and point it to the website for *Paths*.
5. Administer the game. During the experiment detailed interaction data will be logged on the game server. During the entire session the participant will be encouraged to ask questions.
6. Administer the Closing Questionnaire (see Appendix A).
7. Debriefing—Thank the participants for their time and give them their compensation.

1. Clarifying the goal of the game by creating some simple instructions that would be read at the beginning of the game. As one participant in the pilot study stated, "Not understanding the goal was frustrating – made me feel my chances of success were only slightly above random"
2. Improving the *create team spirit* desired characteristic of the game in the following ways. We consolidated the team colours – previously each player had a different colour. The purpose of the different colours was initially done to uniquely identify each player in the game and to aid each player to easily find their piece on the cinema screen. However, in practice this turned out to be unnecessary and resulted in confusion during game play. As one participant suggested: "One thing that might make it easier to keep track of who's team you are on is to have different colour for each team's AI (red vs. blue)." This was done and the refined game layout is shown in Fig. 12.
3. Refining the ball-throwing feature by providing clearer instructions on the mobile device and decreasing the level of accuracy needed to receive a pass. This was accomplished by increasing the area around the receiving player's piece that constitutes a successful catch of the ball.

Table 6
Pilot study closing questionnaire summary results.

Pilot study summary results		
	Metric	%
1.	Personal engagement	93
2.	Crowd engagement	93
3.	Easy to learn	57
4.	Easy to play	40
5.	Ease of reaching goal	63
6.	Challenging	67
7.	Mental demand	50
8.	Timing of game play events and transitions	50
9.	Personal performance	83
10.	Effort	63
11.	Frustration	23

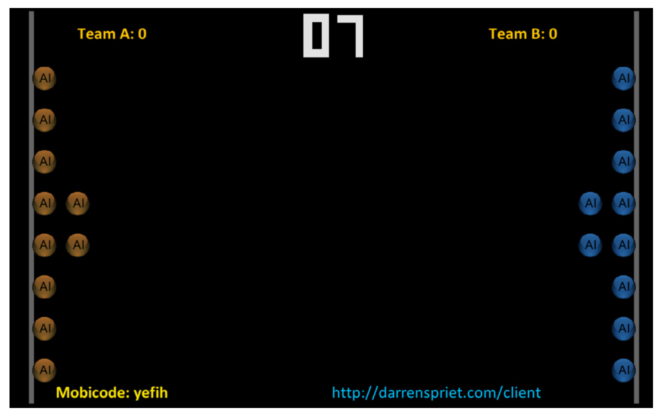

Fig. 12. Refined game layout with 20 AI players illustrating Team A and B using colours (red and blue respectively). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

7.2. Main experiments

Three main experiments were conducted in this study. Each of these main experiments was a complete representation of the whole experiment as in the pilot study. There were approximately 1-month time gaps between these experiments to ensure that participant feedback, researcher's logbooks, and client–server low-level data logs were diligently analyzed. This analysis informed the refinement of *Paths* for the next experiment.

7.2.1. Main experiment #1

Summary of Results – Researchers' observations and perspectives

- The researchers observed audience suspense, excitement and laughter during many scenes involving near misses, innovative paths, last-second finishes and awesome pileup collisions.
- Since all the AI players travel at the same rate, a prominent strategy used by human players was to immediately slow down at the beginning, wait for the AI players to collide and disappear and then proceed. A secondary strategy was a team approach in which one player would purposely speed ahead and cause a collision to clear a path for another teammate.
- There was increased crowd engagement during the Varying Speed and Ball-Throw rounds. The participants seemed to enjoy this part of the game the most, based on feedback from surveys and the researcher's observations.

The following section provides representative comments from participants of the main experiment #1.

Positive comments:

1. "Keep it up! Great work. I want to see it again and play it! Can't wait until it is in the movie theatres!!"
2. "This was an awesome experience—I really enjoyed the game—can't wait to see it in the cinemas!"
3. "Really AWESOME Game!! I want to play it with more people!"
4. "Very fun!! It was fun to get involved individually and as an entire group in the theatre!"

Table 5
Standard descriptive statistics for AI and human player success rates (out of 100) for pilot study—mean and *(standard deviation)*.

	Sit back and relax rounds		Varying speed rounds		Varying speed and ball-throw rounds	
	Round 1	*Round 2*	*Round 3*	*Round 4*	*Round 5*	*Round 6*
AI players	20.23	25.34	28.29	25.25	22.63	21.63
	(7.25)	*(9.36)*	*(6.48)*	*(8.63)*	*(7.35)*	*(8.92)*
Human players	30.21	35.34	43.33	39.53	34.25	32.05
	(7.57)	*(9.35)*	*(6.64)*	*(8.86)*	*(9.34)*	*(8.53)*

5. "Very Fun! Potential for a lot of strategies. Engages your coordination and cooperation with others in the theatre."

Negative comments:

1. "The only thing that took away from the experience was that my phone had difficulty connecting and staying connected."
2. "The fast and slow buttons could be left and right instead – this may make it easier to reach with either thumb. Sometimes the path on my device wouldn't draw the path or it would get cut off."
3. "Sometimes the speed controls did not seem as responsive as they could be, and I had to look down to see how fast I was going."

Beyond the comments gathered from the participants, statistical analysis based on the closing survey was also performed. Table 7 depicts the summary statistics of this qualitative survey. There were a number of interesting observations that result from the analysis of this data. The following are the most significant ones.

1. 93% of the participants personally felt "engaged" or "very engaged" in playing the game.
2. 93% of the participants felt the entire audience was "engaged" or "very engaged."

The areas that were identified for improvement were:

1. Refine the UI for the mobile device to reduce the amount of direct eye contact required. The goal during game play was to truly use the device as a controller that would require little to no eye contact. Our design goal was to have all participants view the cinema screen as much as possible.
2. The user interface for drawing a path was refined based on user observations. Some users were confused when they pressed the "Go" button and expected their piece to start moving on the large screen. The "Go" button actually meant that it was successfully submitted to the game server. In this iteration of the refinement of Paths, the "Go" button was replaced by "Send" which we a clearer UI communication mechanism. Once the user pressed "Send" and was confirmed successfully received by the game server, the "Send" button was changed to "Sent" and became disabled.
3. Resolve the technical issues (i.e., network connectivity issues and path drawing on the device)

7.2.2. Main experiment #2

Summary of Results – Researchers' observations and perspectives

- Overall, the experiment was very successful – we observed audience suspense, excitement and laughter throughout the game. The majority of the participants said they were very pleased with the game and would play it if it were available in the cinema theatres.
- The same strategies as in the previous experiment were used by the majority of players, however, some new strategies emerged, such as immediately slow down at the beginning, traverse to the very top of the screen and continue horizontally to the finish line.
- The rounds that produced the greatest crowd engagement was during the *Varying Speed and Ball-Throw* rounds.

Table 7
Main experiment #1 closing questionnaire summary results.

Main experiment #1 summary results		
Metric		%
1.	Personal engagement	93
2.	Crowd engagement	93
3.	Easy to learn	43
4.	Easy to play	40
5.	Ease of reaching goal	63
6.	Challenging	67
7.	Mental demand	50
8.	Timing of game play events and transitions	60
9.	Personal performance	83
10.	Effort	63
11.	Frustration	23

Table 8
Main experiment #2 closing questionnaire summary results.

Main experiment #2 summary results		
Metric		%
1.	Personal engagement	80
2.	Crowd engagement	90
3.	Easy to learn	67
4.	Easy to play	60
5.	Ease of reaching goal	67
6.	Challenging	67
7.	Mental demand	53
8.	Timing of game play events and transitions	93
9.	Personal performance	67
10.	Effort	73
11.	Frustration	43

The following section provides representative comments from participants of the main experiment #2. Table 8 depicts the summary statistics of this qualitative survey.

Positive comments:

1. "A lot of fun!!! Some interesting strategies emerged from the audience."
2. "Very interesting and challenging as the group figures strategies out."
3. "Very entertaining!!! Fun not knowing the paths of other players."
4. "I liked the team work and laughter!."

Negative comments:

1. "Not sure how points are awarded."
2. "[The mobile device] screen occasion shifts out of place and needed to be titled upright then back to refresh."
3. "More ball control would be good – It's awkward to look @ the big screen and watch and have the controls on the device (just for the ball throw rounds)."
4. "It was easy but not clear how the game was being scored."
5. "Some visual instructions would be nice."

The areas that were focused on for improvement after this experiment were:

1. To provide additional incentive for players to draw efficient paths and to reward those players who reach their respective end zones in first, second and third place positions by granting additional points (See Fig. 13). These top performers receive "4x," "3x," and "2x" individual score multipliers respectively. This is shown on the cinema screen with text animations flying

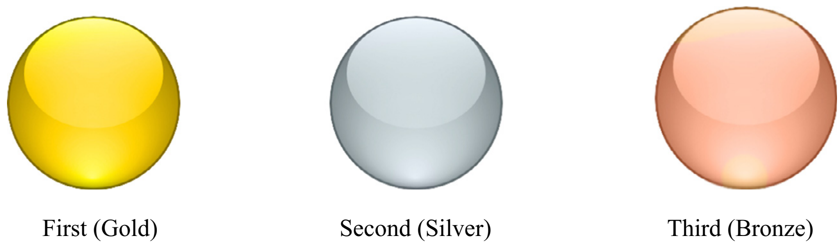

Fig. 13. First, Second and Third place pieces providing incentive to complete the task as quickly as possible.

out from the respective pieces to convey the rewards and to provide incentive for others in the audience to consider good path designs.
2. We refined the AI players to move at random speeds as well as random directions—now AI player would move sometimes fast, sometimes slow throughout the game. This introduced a degree of randomness and unpredictability similar to human players.
3. On the cinema screen, visual instructions with animations were created so that the user would have an even easier time in learning how to interact with the mobile device UI. On the mobile device, a notice "Please look up" ensured the participant would see the instructions on the cinema screen.
4. Resolve the technical issues (mobile screen orientation and refresh issues)

7.2.3. Main experiment #3

Summary of Results – Researchers' observations and perspectives

- Overall, the experiment was very successful – we observed participants becoming increasingly engaged as the game went on and saw the teams work together. After the experiment, several participants wanted to play the game repeatedly.
- The majority of players used the same strategies as in the previous experiment; however, some new strategies emerged because the AI players now exhibited random speeds. Some players would charge ahead and create a path for a teammate, while others would hold back and see if collisions would occur so a clear path would emerge.
- As before, the parts of the game that produced the greatest crowd engagement were the *Varying Speed and Ball-Throw* rounds.

The following section provides comments from participants of the main experiment #3. Table 9 depicts the summary statistics of this qualitative survey.

Table 9
Main experiment #3 closing questionnaire summary results.

Main experiment #3 summary results		
Metric		%
1.	Personal engagement	91
2.	Crowd engagement	93
3.	Easy to learn	73
4.	Easy to play	68
5.	Ease of reaching goal	66
6.	Challenging	58
7.	Mental demand	43
8.	Timing of game play events and transitions	100
9.	Personal performance	75
10.	Effort	56
11.	Frustration	31

Positive comments:

1. "Great game!! Very easy to pickup and play. Would play in a theatre before a movie any day!!!"
2. "Would play in theatre, 100% love to play again."
3. "Really good game!! Better than any "FPS" [First Person Shooter] would love to play again. 10/10 Bravo!"
4. "Awesome game!! Simple but very fun!! Much better than Flappy Bird for instance."
5. "The game worked amazingly well -- couldn't believe that it runs on so many different devices so well!"
6. "Game was unique! Very interactive! (especially with other people) Very fun experience!"
7. "Awesome game! I'd love to play it again in the theatres!"
8. "Very Cool Game!!!"

Negative comments:

1. "Lack of on-screen text [instructions] makes it difficult to learn, but [the] simple controls mitigate this."

After this experiment the following areas were focused on the following:

1. Over the course of the study, we observed the time users spent looking up at the cinema screen versus the time spent on their smartphone as well as the number of times the users switched between the two. Ideally, we hoped that the smartphone controls would become so intuitive and simple to use that the user would simply not need to look at the smartphone screen at all (as is the case with controllers in game consoles such as Xbox, PS4, etc.). Nonetheless, significant progress was made towards this goal: By the end of rounds in the *Varying Speed* mode (Fig. 6), virtually all of the users were constantly looking up at the cinema screen while using the smartphone to control their piece. However, during the *Ball-Throw* rounds (Fig. 7), we observed users looking down at their smartphone and back up at the large display particularly when they were preparing to throw the ball. We therefore focused our attention on improving the ball-throwing interface. This interface was improved by decreasing the sensitivity of the dial for aim and increasing the size of the "throw" button. Ad hoc user reviews of the updated interface indicate that this new interface reduces direct smartphone visual attention and therefore promotes further engagement with the large cinema screen.
2. We also observed that occasionally users would draw a path on their smartphone but fail to press the "Send" button (Fig. 3). We revised the path drawing process to automatically send the last completed path to the game server (i.e., user draws a path using his/her finger from their piece to the "End Zone"). This enabled opportunities for users to change their paths if they wished until the time elapsed for that portion of the game. This new process reduced user errors since a button was no longer needed to be pressed to send the path to the server.

3. We also worked on improving the scalability in *Paths*. For large numbers of users (50+), *Paths* will automatically scale down the visual size of the pieces on the large display. The numbers on each piece that uniquely identify each player are also scaled down but at a lower rate because we discovered that it is very important that that information remain as large as possible. We believe this facilitates easier visual tracking for multiplayer environments that are actively visually complex. Evidence that this is a sound approach may be found in: [32,38].

8. Discussion

In this paper we presented the design, development, refinement and evaluation of *Paths*, a multi-player real-time cinema based game. *Paths* was created using an agile development process. We shared the results of a rigorous scientific evaluation of the game created. Another contribution of this work is through an architectural model for others who wish to create cinema games using mobile devices. The generalizability of the work spans the following areas: (1) a common generic architecture for cinema based games that use smartphones; (2) a common generic scientific methodology for the evaluation of these types of games; and (3) visual scalability.

8.1. A common generic architecture for cinema based games that use smartphones

In Section 6.1, an architectural model was presented from which *Paths* was created. One of the overarching goals in this work was to design and develop an architecture that supports multiple clients (using any mobile device) and a large cinema screen (game server). This architectural model was designed in such a way that game specific details were abstracted away as much as possible. This is a common design approach in computer science and software engineering [39]. As a result, by design, there is great flexibility, and ease with which, to swap in a new game using this framework. For example, the model provides a communication mechanism between the Game Server and Mobile Device clients that is mutually exclusive and independent of game specific details.

As with most architectural models, an inherent part of this architectural model is scalability [39]. It is an inherent design criteria in which several hundred (up to 500 theoretically) concurrent players may fully participate in the game.[4] This architecture provides the foundation for a host of other cinema-based games—all using this common architecture. In this way we believe that generalizability and scalability have been achieved. Furthermore, our framework has been fully implemented and the source code is publically available via BitBucket [35]. The implemented framework may be easily downloaded from the Internet for anyone interested in developing games for cinema theatres (please see: [35]).

8.2. A common generic scientific methodology for the evaluation of cinema based games

To a somewhat lesser degree, we have also shared a generic scientific approach that may be used as a blueprint for setting up a scientific experiment to evaluate a cinema based game. For instance, the same experiment design, instruments, and analysis techniques may be used in other similar studies. This blueprint would serve as platform on which similar studies could be conducted to validate (or invalidate) the findings from this and other related research. This platform would be especially useful at this nascent stage because there are so few of these types of games currently available and even fewer rigorous scientific studies that have been conducted.

8.3. Visual scalability of Paths

Beyond these contributions, we also explored the degree to which scalability of *Paths* is supported from a low-level game specific perspective. One of the decisions made early on in the development of *Paths* was the requirement that simplicity and clarity of the user's representation were paramount for both the smartphone and the large display. This is one of the key reasons why we choose very plain and simple round pieces. They are psychologically familiar and simple [32,40]. They are also based on pieces used in extremely popular games such as Checkers, which is a game very familiar to a vast number of people [32]. We discovered that this uncomplicated graphical representation is important when engaging concurrent participants in gameplay. We did not receive any criticisms from participants regarding their ability to immediately track to his/her piece on the smartphone and also on the cinema screen. All participants seemed very comfortable and capable of tracking their piece regardless of the number of concurrent players.

In our design of *Paths*, as the number of concurrent players increases, the size of the pieces decreases yet the important identifiable number remains proportionally larger. This facilitates quick and easy identification of the piece on the cinema screen even when there are many concurrent players (e.g., 50+).

Figs. 14–19 show simulated runs of 50, 70 and 100 players. Each of these figures are paired showing the initial layout of the game before any piece has moved and a screen capture of gameplay with that number of pieces in motion. It is important to note that even with these numbers of players, in each scenario the pieces are all easily identifiable and during gameplay it was quite easy to track any of the individual pieces as they travelled their path.

Furthermore, as shown in the case with 100 players (Fig. 19), the trailing path for the pieces that are ahead of other pieces was significantly reduced to avoid visual interference with other pieces. This assists in providing visual clarity for all participants.

There is however, an upper bound to the number of people that can concurrently participate in the game. For example, it is not likely feasible for 500 people to play *Paths* even though theoretically the architectural model could support it. In its present form, the number of players that *Paths* can accommodate is limited by the following constraints:

1. The radius of the piece cannot be so small that participants have difficulty tracking pieces on the screen. The current layout scheme imposes a minimum radius. This minimum radius is based on our research findings of being able to easily track a piece while situated at the back row in a typical movie theatre. (For our purposes, we used a theatre that seats 200 people (approximately 270 m^2/2,900 ft^2) and the distance from the cinema screen to the back row is approximately 20 m.)
2. The number of players that can fit within a column cannot be so high that the players are too close together. The current layout scheme imposes a limit on this as well.
3. The columns cannot be positioned too close to each other nor can columns from opposing teams overlap.

We also explored ways in which marketing, advertisement and monetization models could be incorporated into the game, but it was not a focus of this research. For instance, as shown in Fig. 17, when a collision occurs between two pieces, popcorn flies up and out to the sides of the screen and down to the bottom using

[4] This is based on (1) the computational resources typically available on current day game server systems and (2) the network bandwidth throughput requirements to support intense client-server communications over WiFi.

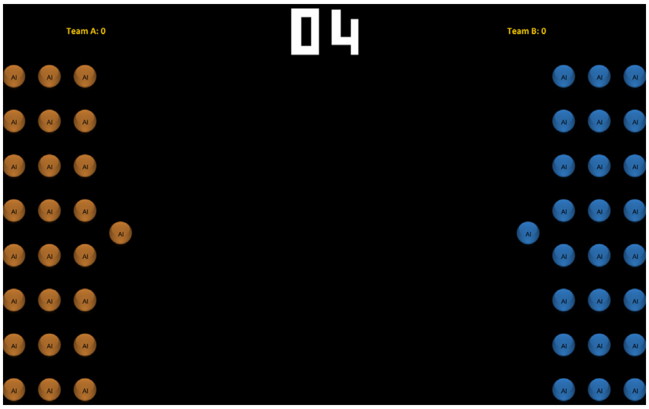

Fig. 14. Initial layout with 50 players (25 per side).

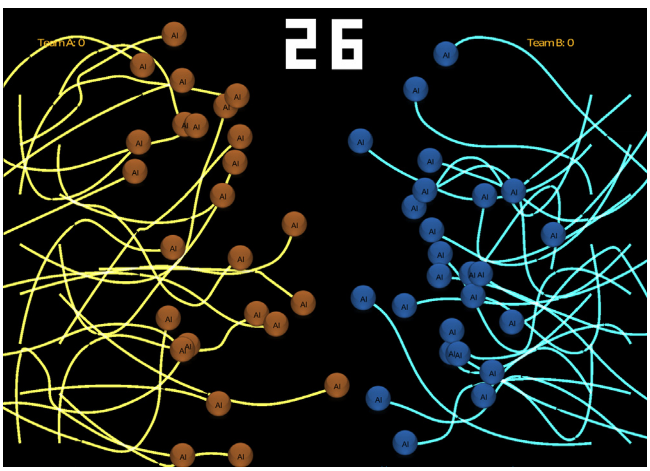

Fig. 15. Simulated run with 50 players. Each player remains easily identifiable.

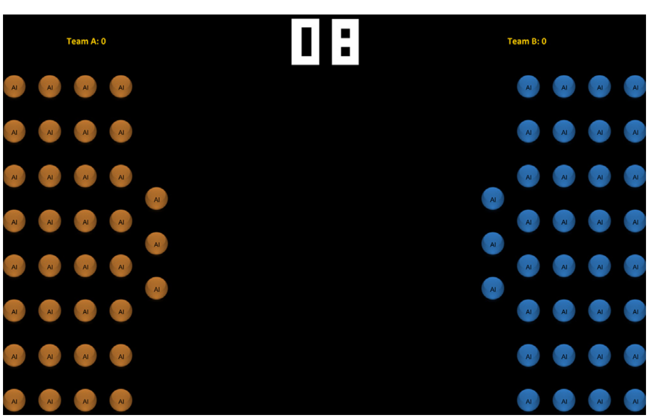

Fig. 16. Initial layout with 70 players (35 per side).

the inspiration of actual popcorn machines. At the same time, a loud "pop" is heard resembling the sound of popcorn "popping." We thought this was creative, light and entertaining. We certainly did not over-analyze this component of the game, however, one could argue that this may contribute to some level of subliminal marketing to encourage patrons to purchase popcorn at the concession stands before the movie starts.

We also explored to a small degree a financial model that could be incorporated into *Paths*. The monetization model could include a combination of a platform license fee as well as participation in

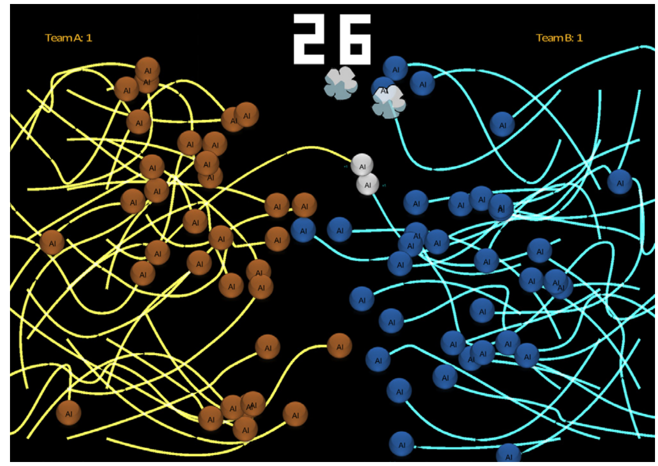

Fig. 17. Simulated run with 70 players. Each player remains identifiable.

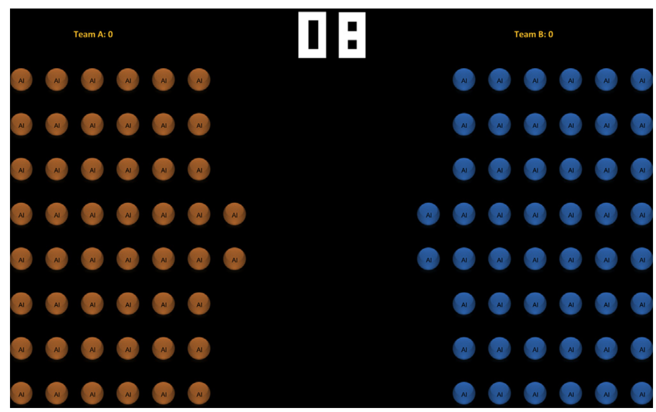

Fig. 18. Initial layout with 100 players (50 per side).

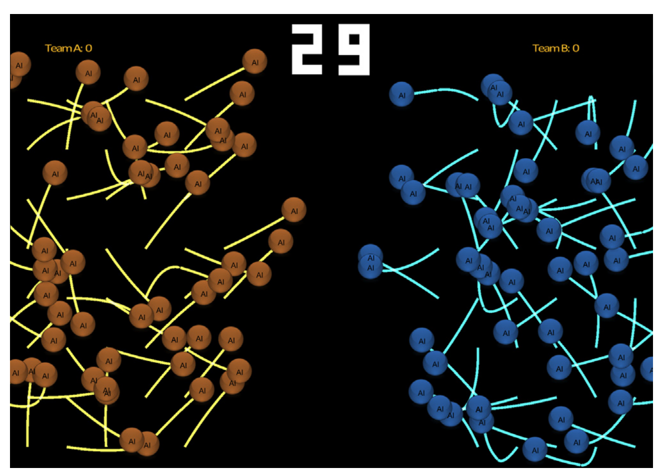

Fig. 19. Simulated game play with 100 players. Each player remains identifiable.

playing the game in movie theatres. The platform license costs could be supported through subsidization by the host movie theatre and/or individual patron's purchasing and using the app.

An advertising model could promote the entertainment offering to attract patrons, increase frequency, create promotional opportunities and deliver incremental revenues. Content in *Paths* could be customized and personalized with sponsorship that would be tied to offers (e.g., movie coupons, concession product vouchers, etc.), thus creating revenue opportunities.

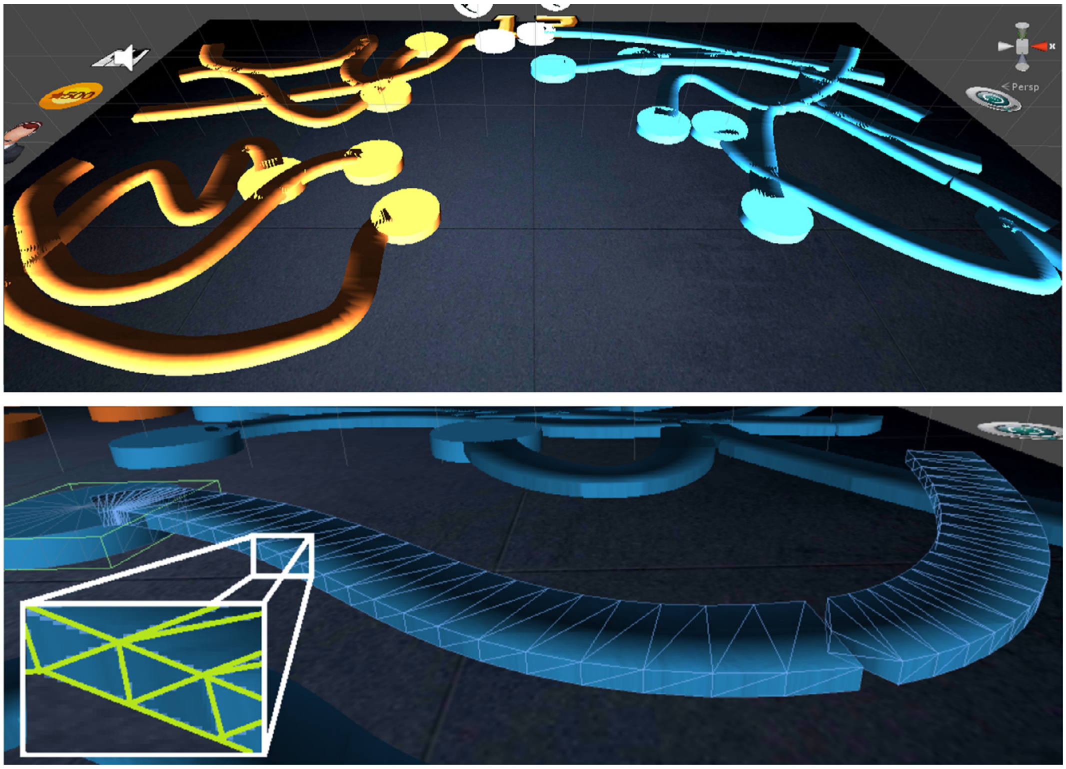

Fig. 20. *Paths 3D* – 3D mesh representations of a future version of *Paths*.

9. Conclusion

The pre-show period is becoming an increasingly important part of the movie-going experience and the film industry itself. However, an increasing number of moviegoers are finding the pre-feature period disengaging. The time is right for the pre-show period to harness the opportunity of social networking and personal interactive technologies. Since 2005, the pre-movie in-theatre experience has grown to over a half-billon dollar industry and this growth has shown no signs of subsiding. Consequently, there is an industry-wide demand for innovation in the pre-movie area.

In this paper, we presented *Paths,* an innovative multiplayer real-time socially engaging game that we designed, developed and evaluated. An iterative refinement application development methodology was used to create the game. The game may be played on any smartphone and group interactions are viewed on the large theatre screen. The design of the game was guided by the desirable characteristics: *movie theatre contextual environment*; *ease of learning*; *ease of use*; *crowd engagement*; *creation of team spirit* (collaboration) and *rivalry* (team competition); *feasibility*; and *scalability*.

This paper also reports on the quasi-experimental mixed method study with repeated measures that was conducted to ascertain the effectiveness of this new game. The results show that the game is very engaging with elements of suspense, pleasant unpredictability and effective team building and crowd-pleasing characteristics.

The contributions of this work include:

1. the creation of a common openly available generic architecture for cinema based games that use smartphones;
2. a common generic scientific methodology for the evaluation of these types of games; and
3. the results of implementing a game using this architecture and evaluating it using this scientific methodology.

Two videos of the final version of *Paths* being played in a theatre environment by 22 and 28 participants respectively are found here: http://www-acad.sheridanc.on.ca/~sykes/research.html

9.1. Future work

We have additional experiments scheduled for later in 2015 and others in 2016. We are excited to continue this research to determine how to improve *Paths* so that the participant engagement and satisfaction is further increased. The same survey design would be used to ensure consistency in the experiment. Our ultimate goal is to test *Paths* with 100 or more human players.

Using a sophisticated tool like Unity makes it quite straightforward to provide a visually beautiful and eye-catching experience for the user. One idea that we explored was a prototype to showcase *Paths* in 3D. We discovered that we could reuse much of the existing code base and just change the various game artefacts to render everything in 3D instead of 2D. The main challenge here was figuring out how to generate the paths in 3D. Whereas previously, we had been using a `LineRenderer` to draw our paths in "billboard" fashion (i.e. without any possibility of adapting to a 3D perspective), now we had to come up with a new rendering process. We decided to experiment with procedural mesh rendering where we build the path by surrounding each 3D coordinate within a square and then connecting the corners of these squares to produce a 3D mesh. The results were spectacular as can be seen in the screenshot of the prototype (Fig. 20).

Acknowledgement

We gratefully acknowledge the financial support from Natural Sciences and Engineering Research Council of Canada (NSERC). The NSERC Applied Research and Development grant (level 1) provided the support to engage the students and industry partner in creating this innovation game for cinema theatres.

Appendix A. Closing questionnaire survey sheet

Title of study: Mobile devices at the cinema theatre

This survey is used to determine the effectiveness of the *Paths* game – Mobile Devices at the Cinema Theatre. For each question, select the most appropriate response based on the following scale:

1 = strongly favourable to the concept, 2 = somewhat favourable to the concept, 3 = undecided, 4 = somewhat unfavourable to the concept, 5 = strongly unfavourable to the concept.

1. How engaged were ***you*** in playing the game?				
Not very engaged				Very engaged
1	2	3	4	5
Please share any additional comments:				
2. How engaged do you think ***the audience*** was?				
Not very engaged	Very engaged			
1	2	3	4	5
Please share any additional comments:				
3. How easy was it to ***learn*** how to play the game?				
Very easy				Very hard
1	2	3	4	5
Please share any additional comments:				
4. How easy was it to ***play*** the game?				
Very easy				Very hard
1	2	3	4	5
Please share any additional comments:				
5. Game difficulty: How easy was it to ***reach the goal of the game*** (eg., for your Team to win)?				
Very easy				Very hard
1	2	3	4	5
Please share any additional comments:				
6. Game Challenge—How ***challenging*** was the game?				
Very little challenge				Very challenging
1	2	3	4	5
Please share any additional comments:				
7. Mental Demand—How mentally demanding was the game?				
Very low				Very high
1	2	3	4	5
Please share any additional comments:				
8. Timing: What is your opinion of the ***timing of the game play***?				
Very slow		Just right		Very fast
1	2	3	4	5
Please share any additional comments:				
9. Performance—How successful do you feel you were in ***succeeding*** in the game?				
Not Successful				Very Successful
1	2	3	4	5
Please share any additional comments:				
10. Effort—How hard did you have to work to accomplish your level of performance?				
Very little work involved				Worked very hard
1	2	3	4	5
Please share any additional comments:				
11. Frustration —How insecure, discouraged, irritated, stressed, or annoyed were you?				
Very low				Very high
1	2	3	4	5
Please share any additional comments:				
Please share any additional comments regarding this study:				

Appendix B. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.entcom.2016.02.004.

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